

SPILL AND DYKE EROSION WATER STORAGE RESERVOIR NO. 2 KEY LAKE MINESITE, SASKATCHEWAN

JANUARY, 1984

FILE NO. S84-649



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SPILL AND DYKE EROSION
WATER STORAGE RESERVOIR NO. 2
KEY LAKE MINESITE, SASKATCHEWAN
JANUARY 30, 1984 FILE NO. S84-649

PREPARED FOR:

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EXECUTIVE SUMMARY

The Key Lake Mining Corporation operates two water storage reservoirs with a combined design full capacity of 358,000 cubic metres. During the plant maintenance shutdown water from Gaertner pit was being pumped into the reservoirs. On the night of January 4/5, 1984 the south end of the west dyke of Water Reservoir No. 2 was overtopped. The sandy dyke fill eroded rapidly, deformed the liner and released 87,300 cubic metres of water contaminated with Radium 226.

The spill water flowed to Gerald Lake and displaced water into the adjacent muskeg area. A temporary dyke, constructed immediately after the spill on the existing road across the muskeg area, contained the spill water. This temporary containment dyke was reinforced on January 7, 1984. The temporary dyke, road and some of the spill/displaced waters are frozen in the muskeg area. In the frozen state the road and temporary dyke has contained the spill. The temporary dyke is not considered adequate to contain the estimated 200,000 cubic metres of spring runoff water from the 1.3 square kilometre local drainage basin of Gerald Lake.

It is recommended that the spill water be collected and pumped into Reservoir No. 1, or the Tailings Management Reservoir. The Gaertner pit is an emergency alternative. Chemical treatment of spill water on site may be necessary. Water sampling and chemical analysis should establish the treatment requirements.

A field survey and a review of the design and "as constructed" drawings revealed that the elevation of the exterior dyke was 539.00 metres except at the breach where the dyke elevation was 200 mm lower. A spillway, across the dividing interior dyke common to both reservoirs, was at elevation 538.2 metres rather than 537.50 metres as

shown on the design operating and "as constructed" drawings. The higher spillway elevation of 538.2 metres and the dyke elevation of 538.8 metres at the breach location provided a localized freeboard of only 600 mm. The design freeboard was 1.5 metres.

The stability of the remaining dykes of Reservoir Nos. 1 and 2 under design service conditions is well above the minimum accepted in engineering practice. However, sand/gravel fill dykes subjected to water flow erode rapidly as evidenced by this occurrence. The proposed repair of the breached dyke has been approved and repairs are in progress.

Recommendations for operation of the two reservoirs include:

1. Maintain minimum freeboard of 1.5 metres.
2. Install water level indicator systems in the reservoirs.
3. Maintain water level in Reservoir No. 1 sufficiently below maximum operating level to ensure adequate storage capacity for surface runoff.
4. Conduct a general review of the design and construction of dykes using granular fill soils and synthetic liners and provide protection against erosion of dykes for the designed long term performance.
5. Review potential areas of spills to establish the maximum volume of the most probable spill and provide a supplementary spill collection and holding reservoir together with a contingency plan for cleanup of any such spill.

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1.0 INTRODUCTION

The following report is submitted on the water spill resulting from overtopping and erosion of the west dyke of Water Storage Reservoir No. 2 at the Key Lake Mining Corporation facility, Key Lake, Saskatchewan. This report deals with the January 4/5, 1984 spill of a calculated volume of 87,300 cubic metres of water containing Radium 226. This report is based on site inspections conducted on January 7, and January 13, 1984, and, a review of design drawings contained in a preliminary report entitled "Water Storage Reservoir Construction Report", dated January 24, 1983 as prepared by Knight and Piésold Ltd. Photograph No. S84-649-1P shows Gerald Lake and muskeg area probably affected by the water spill.

2.0 DESCRIPTION OF WATER RESERVOIRS

Two reservoirs, separated by a common interior dyke, were constructed for storage of water. The combined design full capacity of the two reservoirs was 358,000 m³. The combined maximum design operating capacity of the two reservoirs, with a minimum freeboard of 1.5 metres was 280,000 m³. At the design operating capacity elevation of 537.50 metres the calculated volume of water stored in Reservoir No. 1 would be 185,000 m³, while the calculated volume in Reservoir No. 2 would be 90,000 m³. The location of the reservoirs and the mill are shown on Photograph No. S84-649-2P.



PHOTO NO. S84-649-1P - Aerial view of Mill, Reservoir Nos. 1 and 2, Gerald Lake, Wolf Lake breached dyke, drainage channel across muskeg and temporary containment dyke (January 7, 1984)



PHOTO NO. S84-649-2P - Aerial view of Mill, Reservoirs, breached dyke and temporary containment dyke (January 7, 1984)

2.1 Sources of Water Stored in Reservoirs

Prior to start of the milling process, the reservoirs stored water from the Gaertner open pit, the Special Waste Stockpile Facility and the Ore and Cobble Ore Stockpile Facility. During operation Reservoir No. 1 is being used to store surface run-off from the mill area terrace as well as any contaminated water from the open pit and stockpile facilities. Reservoir No. 2 was designed to store supernatant liquid from the Tailings Storage Facility along with the recycled water from the mill operations and the monitoring ponds.

2.2 Design Details of Reservoirs

With reference to the "as constructed" drawings, the elevation of the top of the reservoir dykes was 539.00 metres. The interior dyke, common to Reservoir No. 1 and Reservoir No. 2, had a 15.0 metre wide spillway to allow for drainage of water from Reservoir No. 1 to Reservoir No. 2 or vice versa. Under normal operating conditions the water level in one of the reservoirs would be maintained at a level

The predominant surficial soil deposits at the Key Lake Minesite consisted of sandy glacial till, sand and gravel deposits. These natural deposits were processed and were used for all the structural earth fill construction at the minesite. These granular soils are highly permeable and the fine grained fraction (finer than gravel) is highly susceptible to erosion.

1977-1978-1979-1980-1981-1982-1983-1984-1985-1986-1987-1988-1989-1990-1991-1992-1993-1994-1995-1996-1997-1998-1999-2000-2001-2002-2003-2004-2005-2006-2007-2008-2009-2010-2011-2012-2013-2014-2015-2016-2017-2018-2019-2020-2021-2022-2023-2024-2025-2026-2027-2028-2029-2030-2031-2032-2033-2034-2035-2036-2037-2038-2039-2040-2041-2042-2043-2044-2045-2046-2047-2048-2049-2050-2051-2052-2053-2054-2055-2056-2057-2058-2059-2060-2061-2062-2063-2064-2065-2066-2067-2068-2069-2070-2071-2072-2073-2074-2075-2076-2077-2078-2079-2080-2081-2082-2083-2084-2085-2086-2087-2088-2089-2090-2091-2092-2093-2094-2095-2096-2097-2098-2099-2100-2101-2102-2103-2104-2105-2106-2107-2108-2109-2110-2111-2112-2113-2114-2115-2116-2117-2118-2119-2120-2121-2122-2123-2124-2125-2126-2127-2128-2129-2130-2131-2132-2133-2134-2135-2136-2137-2138-2139-2140-2141-2142-2143-2144-2145-2146-2147-2148-2149-2150-2151-2152-2153-2154-2155-2156-2157-2158-2159-2160-2161-2162-2163-2164-2165-2166-2167-2168-2169-2170-2171-2172-2173-2174-2175-2176-2177-2178-2179-2180-2181-2182-2183-2184-2185-2186-2187-2188-2189-2190-2191-2192-2193-2194-2195-2196-2197-2198-2199-2200-2201-2202-2203-2204-2205-2206-2207-2208-2209-2210-2211-2212-2213-2214-2215-2216-2217-2218-2219-2220-2221-2222-2223-2224-2225-2226-2227-2228-2229-2230-2231-2232-2233-2234-2235-2236-2237-2238-2239-2240-2241-2242-2243-2244-2245-2246-2247-2248-2249-2250-2251-2252-2253-2254-2255-2256-2257-2258-2259-2260-2261-2262-2263-2264-2265-2266-2267-2268-2269-2270-2271-2272-2273-2274-2275-2276-2277-2278-2279-2280-2281-2282-2283-2284-2285-2286-2287-2288-2289-2290-2291-2292-2293-2294-2295-2296-2297-2298-2299-2300-2301-2302-2303-2304-2305-2306-2307-2308-2309-2310-2311-2312-2313-2314-2315-2316-2317-2318-2319-2320-2321-2322-2323-2324-2325-2326-2327-2328-2329-2330-2331-2332-2333-2334-2335-2336-2337-2338-2339-2340-2341-2342-2343-2344-2345-2346-2347-2348-2349-2350-2351-2352-2353-2354-2355-2356-2357-2358-2359-2360-2361-2362-2363-2364-2365-2366-2367-2368-2369-2370-2371-2372-2373-2374-2375-2376-2377-2378-2379-2380-2381-2382-2383-2384-2385-2386-2387-2388-2389-2390-2391-2392-2393-2394-2395-2396-2397-2398-2399-2400-2401-2402-2403-2404-2405-2406-2407-2408-2409-2410-2411-2412-2413-2414-2415-2416-2417-2418-2419-2420-2421-2422-2423-2424-2425-2426-2427-2428-2429-2430-2431-2432-2433-2434-2435-2436-2437-2438-2439-2440-2441-2442-2443-2444-2445-2446-2447-2448-2449-2450-2451-2452-2453-2454-2455-2456-2457-2458-2459-2460-2461-2462-2463-2464-2465-2466-2467-2468-2469-2470-2471-2472-2473-2474-2475-2476-2477-2478-2479-2480-2481-2482-2483-2484-2485-2486-2487-2488-2489-2490-2491-2492-2493-2494-2495-2496-2497-2498-2499-2500-2501-2502-2503-2504-2505-2506-2507-2508-2509-2510-2511-2512-2513-2514-2515-2516-2517-2518-2519-2520-2521-2522-2523-2524-2525-2526-2527-2528-2529-2530-2531-2532-2533-2534-2535-2536-2537-2538-2539-2540-2541-2542-2543-2544-2545-2546-2547-2548-2549-2550-2551-2552-2553-2554-2555-2556-2557-2558-2559-2560-2561-2562-2563-2564-2565-2566-2567-2568-2569-2570-2571-2572-2573-2574-2575-2576-2577-2578-2579-2580-2581-2582-2583-2584-2585-2586-2587-2588-2589-2590-2591-2592-2593-2594-2595-2596-2597-2598-2599-2600-2601-2602-2603-2604-2605-2606-2607-2608-2609-2610-2611-2612-2613-2614-2615-2616-2617-2618-2619-2620-2621-2622-2623-2624-2625-2626-2627-2628-2629-2630-2631-2632-2633-2634-2635-2636-2637-2638-2639-2640-2641-2642-2643-2644-2645-2646-2647-2648-2649-2650-2651-2652-2653-2654-2655-2656-2657-2658-2659-2660-2661-2662-2663-2664-2665-2666-2667-2668-2669-2670-2671-2672-2673-2674-2675-2676-2677-2678-2679-2680-2681-2682-2683-2684-2685-2686-2687-2688-2689-2690-2691-2692-2693-2694-2695-2696-2697-2698-2699-2700-2701-2702-2703-2704-2705-2706-2707-2708-2709-2710-2711-2712-2713-2714-2715-2716-2717-2718-2719-2720-2721-2722-2723-2724-2725-2726-2727-2728-2729-2730-2731-2732-2733-2734-2735-2736-2737-2738-2739-2740-2741-2742-2743-2744-2745-2746-2747-2748-2749-2750-2751-2752-2753-2754-2755-2756-2757-2758-2759-2760-2761-2762-2763-2764-2765-2766-2767-2768-2769-2770-2771-2772-2773-2774-2775-2776-2777-2778-2779-2780-2781-2782-2783-2784-2785-2786-2787-2788-2789-2790-2791-2792-2793-2794-2795

Because of the high permeability and erosion characteristics of the insitu and locally imported, processed soils, the design of the water reservoirs required special treatment. Hence, the water reservoirs were lined with a synthetic membrane liner.

2.4 Construction of Reservoirs

The Water Reservoirs were located between metric plant co-ordinates 100,200 E and 100,500 E, and, co-ordinates 199,200 N and 199,600 N. The original area sloped downward and drained towards the muskeg area lying north of Gerald Lake. The low elevation of the original ground surface was approximately 529 metres, while the high natural ground surface elevation was approximately 548 metres. The millsite terrace was higher than the elevation of the exterior dykes and was sloped downward towards the Water Storage Reservoirs.

The flat base area of the two reservoirs was excavated to approximately elevation 529.6 metres. Bentonite was then added and blended at a specified moisture content after which the blended

soil was compacted to provide a 200 mm thick bentonite modified underseal. The construction report ¹ indicates that the field and laboratory tests confirmed that the permeability design objective of 1.0×10^{-9} m/sec. had been consistently achieved.

Subsequent to the bentonite underseal construction, a perforated pipe drainage system was installed on top of the underseal and covered with approximately 200 mm of filter sand. The perforated drainage pipes were designed to serve as a seepage collector and leak detection system for any seepage through the synthetic liner.

The dykes were constructed of glacial till and outwash sand. The grain size distribution of the fill, indicating well graded material, is shown on the grain size distribution curves, Figures 3.1 and 3.2 in the referenced (1) report. The specified maximum permissible particle size was 150 mm. A limited number of larger particles were evident in the toe section of the breached dyke. The fill was placed in 300 mm lifts and each lift was compacted using 10 tonne

¹ See pages 7 to 18, inclusive of Water Storage Reservoirs Report dated January 24, 1983 by Knight and Piésold Ltd.

vibratory rollers. The median field dry density to which the fill was compacted was 1.94 t/m³ or a median of 92.3 percent of the laboratory dry density as determined by ASTM D2049 test method.

The Water Storage Reservoirs were constructed during the period April and November 1982. The construction included the installation of 5 monitoring piezometers. A hypalon synthetic rubber sheeting membrane was installed in the ponds in 1982. It is understood that some performance deficiencies were experienced. Consequently, the hypalon membrane was removed and replaced with a 2.5 mm (100 mil in thickness) high density polyethylene liner during the summer of 1983. The robust high density polyethylene liner has performed well as evidenced by the fact that it was necessary to cut the liner after the dyke was breached and the fact that the installed subdrains and piezometers have not indicated any seepage losses to date.

3.0 OPERATION OF RESERVOIR NOS. 1 AND 2

3.1 Capacity of Reservoirs

The Water Storage Reservoirs were designed to contain an operating capacity of 280,000 m³ with a freeboard safety margin of 1.5 metres and a reserve capacity of 78,000 m³. The Water Reservoirs were not equipped with water level indicators or alarm systems designed to alert the mill operators when the water level exceeded the design operating elevation. Each Reservoir could be filled or emptied independently of the other, except that when the water level in either reservoir reached elevation 537.50 m, the water would flow over the spillway into the adjacent reservoir.

3.2 Sources of Process Water

Process water pumped into Reservoir No. 1 was collected from the Gaertner open pit, and, runoff from the mill site and stockpile facilities. Reservoir No. 2 would normally contain supernatant liquid from Tailings Storage Facility, recycled water from mill operations and the monitoring ponds.

3.3 Operating Design Elevations

Under normal operating conditions the water level in Reservoir No. 1 would be maintained close to the operating design elevation (537.50 m), while the water level in Reservoir No. 2 would be maintained well below the 537.50 m operating design elevation to provide adequate short term storage capacity.

3.4 Actual Operating Elevations

The "as constructed" elevations shown on the drawings in the preliminary report (ref. 1) indicate that the top of dyke elevation was 539.00 m. The spillway across the dyke common to Reservoir Nos. 1 and 2 was shown as 537.50 metres. This would provide 1.5 metres of freeboard when the reservoirs are filled to the base of the spillway elevation.

An elevation survey, conducted by Key Lake Mining subsequent to the spill, reported that the elevation of the perimeter dyke was 539.00 metres except at the location of the breach in Reservoir No. 2 at which location the exterior dyke elevation was 538.8 metres. The elevation of the spillway was 538.2 metres. If the reservoirs were operated with the water level at the spillway elevation

of 538.2 metres, then the localized freeboard at the location of the breach in Reservoir No. 2 was only 0.6 metres, or 900 mm less than the recommended and as shown on the "as constructed" drawings provided in the preliminary report entitled "Water Storage Reservoirs Construction Report" (reference 1).

3.5 Operating Conditions Prior to Failure

It is understood that the mill was shut down for scheduled maintenance at the time that the spill occurred. Prior to the mill shutdown the water levels in the reservoirs were probably close to the design operating elevation. As a result of the shutdown, the mill process water and the water from the monitoring ponds was pumped back to the Water Storage Reservoirs. The pumping of seepage water from Gaertner open pit continued during the mill maintenance shutdown. This would have continuously added water to Reservoir No. 1. Since no process water was being used, the water level in Reservoir No. 1 would have continued to rise. Water pumped into Reservoir No. 1, after it filled to elevation 538.2, would have spilled over into Reservoir No. 2. Continued pumping, continued to fill

both reservoirs until the lowest elevation of the exterior dyke was reached. That was elevation 538.8 metres at the south end of the west dyke of Reservoir No. 2. The water then flowed overtop of the dyke.

4.0 SPILL AND EROSION OF DYKE

The spill of water occurred as a result of overtopping of the lowest section of the west dyke of Water Storage Reservoir No. 2 and erosion as a result of the overtopping.

4.1 Dyke Cross-Section

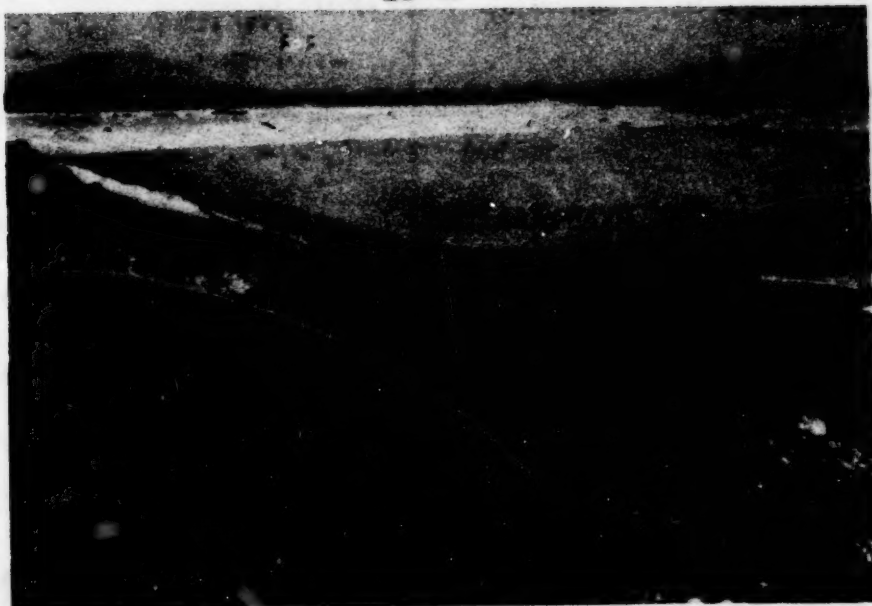
A cross-section of the dyke at the point of failure indicates that the dyke was approximately 9 metres in height with a top width of 10 metres and a base width of approximately 60 metres. The inside face of the dyke (as well as the base of the pond) was lined with a thick, high density polyethylene liner. The dyke fill, observed at the breached section consisted of glacial till and sand, with nominal amount of cobblestones and boulders. Photograph Nos. S84-649-3P, 4P, 5P and 6P show the eroded dyke section.



PHOTOGRAPH NO. S84-649-3P - Breached west dyke of Reservoir No. 2, looking west. Note slabs of ice (approximately 450 mm thick) and snow cover. (January 7, 1984)



PHOTOGRAPH NO. S84-649-4P - Breached west dyke of Reservoir No. 2, looking east. Note: Erosion below frozen dyke. (January 7, 1984)



PHOTOGRAPH NO. S84-649-5P - Breached west dyke looking east towards Reservoir No. 2. NOTE: High density polyethylene liner (black) on inside face of west dyke. (January 7, 1984)



PHOTOGRAPH NO. S84-649-6P - Breached west dyke looking east towards Reservoir No. 2. Note: Final erosion of dyke fill and removal of fine grained soil leaving behind cobbles and boulders. Saskatchewan Environment personnel examining erosion. (January 7, 1984)

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4.2 Mechanics of Dyke Failure

Both Reservoir Nos. 1 and 2 were filled to capacity when the south end of the west dyke of Reservoir No. 2 was overtopped. Once the dyke was overtopped, erosion of the sandy fill started. Progressive erosion of the sandy fill soil continued as shown schematically on Drawing No. S84-649-2.

With reference to Drawing No. S84-649-2, the schematic representation of the erosion of the dyke from elevation 538.8 m to the base of the eroded dyke elevation 534.6 m occurred within a short time interval of a few hours in spite of reported initial efforts to repair the eroding dyke and thereby decrease the total volume of the spill. Once erosion of the dyke started (even though the surface of the dyke was frozen) the dyke quickly eroded to the base of the constructed fill.

Reservoir No. 2 drained to elevation 534.63 (elevation survey provided by Key Lake Mining on January 7, 1984) during the spill. A depth of 4.63 metres of water remained in Reservoir No. 2 after flow through the breached dyke stopped. Prior to start of dyke repairs some water was pumped out of Reservoir No. 2.

①

**NORMAL OPERATING
WATER LEVEL**

DESIGN ELEV. 539.0m

ELEV. 537.5 m



The sandy fill dyke was 9 metres high, 10 metres wide at top and 60 metres wide at the base. Design operating level was 1.5 metres below top.

②

**OVERTOPPING AND EROSION
STARTING AT**

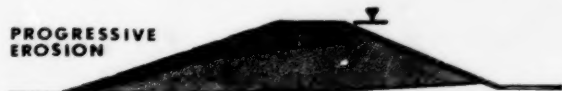
ELEV. 538.8 m



The water level at start of the dyke erosion was full depth of reservoir. The surface of the dyke was frozen and the water flowing on the surface of the dyke eroded through the frozen zone.

③

**PROGRESSIVE
EROSION**



Within a short time interval significant narrow channel erosion would have occurred in the unfrozen fill.

④

**UNDERCUTTING AT
EDGE OF LINER
AND EROSION**



The sequence of events would have accelerated rapidly as flowing water eroded the dyke and undercut the soil under the liner.

⑤

**PROGRESSIVE UNDERCUTTING
AND EROSION**



As soil eroded from under the liner the liner partially deformed. This allowed water flow to increase and erode more soil from under the liner.

⑥

**MOST DYKE FILL
ERODED AND
RESERVOIR
DRAINED**



The majority of the dyke eroded, the liner torn and the reservoir drained to approximately the original ground surface elevation.



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SASKATOON, SASK.

DRAWING TITLE

SCHEMATIC OF PROGRESSIVE EROSION OF DYKE

PROJECT

**SPILL AND DYKE EROSION, WATER STORAGE RESERVOIR NO. 2
KEY LAKE MINESITE, SASKATCHEWAN**

SCALE

1:1000

DATE

JANUARY 20, 1984

DRAWING NUMBER

S84-649-2

4.3 Stability of Dykes

We reviewed the design data and conducted theoretical slope stability analysis using the Slope II computer program available through the Saskatchewan Computer Utility Corporation (Saskcomp) facilities and the University of Saskatchewan, Saskatoon, Saskatchewan. The surface profile was taken from the "as constructed" drawings. Soil data was taken from the Construction Report Summary (ref 1). Additional laboratory test design parameters were provided by Knight and Piésold Ltd. Field and laboratory testing was not within our terms of reference and no tests were conducted. Our review of the test data indicates that the design values were typical of the soil deposits encountered in this area. The soil physical properties used in the theoretical slope stability analysis for the existing dykes and the proposed reconstruction of the breached section of dyke of Reservoir No. 2 were as follows.

SOIL STRATA	TOTAL UNIT WEIGHT (kN/m ³)	UNIT COHESION (kPa)	FRICTION ANGLE (DEGREES)
Insitu Foundation Soil	21.1	0	38 and 41
Original Compacted Dyke Fill	20.6	0	38 and 41
Sand Fill Dyke Repair	17.9	0	31.5
Coarse Fill Dyke Repair	17.9	0	31.5

Using the above soil properties a theoretical stability analysis conducted for the existing Reservoirs, assuming that the Reservoirs were filled to capacity (elevation 539.00 m) and the groundwater table was below the dyke base elevation, yielded a factor of safety* value of 2.3 and 2.7 for soil friction angles of 38 and 41 degrees, respectively.

The theoretical factor of safety decreased to 1.1 for a reservoir filled to capacity and groundwater at elevation 539.00, that is, dyke fully saturated. It should be recognized that this condition is unlikely to

* A factor of safety of 1.0 indicates a metastable condition at which value the probability of occurrence of slope failure is high.

occur in practice since the pervious dyke fill would be eroded by the water very rapidly and the dyke cross section would be lost. Imminent failure would occur as a result of erosion rather than shear failure.

Using the proposed cross-section for the repair of the dyke, the theoretical factor of safety for the repaired dyke section (friction angle 31.5 degrees and density of 17.9 kN/m³) * was 1.9 for normal dry dyke condition of service.

A theoretical analysis conducted for the repaired dyke section saturated to elevation 539.00 (top of dyke) but with the dyke reinforced with a coarse gravel berm yielded a factor of safety of 1.9.

Based on the above analysis, the factors of safety are well above the normally minimum accepted in engineering practice for water retaining earth dyke fill structures.

* values provided by Knight and Piésold Ltd.

5.0 PROBABLE FLOW OF SPILL WATER

5.1 Surficial Evidence

The water from Water Reservoir No. 2 entered the lowest adjacent area, that is, Gerald Lake. Gerald Lake drains to the north towards Wolf Lake. A drainage channel was constructed a few years ago across the muskeg area to improve drainage of Gerald Lake. The drainage channel is shown on Photograph No. S84-649-1P. This drainage channel allowed water to flow into the muskeg area and towards Wolf Lake until it reached the access road to the Tailings Storage Area. The road acted as a barrier.

At the time of preparation of this report the chemical analysis of all the water and sediment samples had not been completed and the exact location of the spill water within the confined area was not known. We expect however, that some of the spill water entered Gerald Lake while some of the water flowed onto the ice and snow cover of Gerald Lake. The increased loading on the ice would have displaced some water from Gerald Lake and allowed the displaced water to enter the drainage channel. Similarly, any water entering Gerald Lake would have displaced some of the lake water. The displaced lake water would have followed the

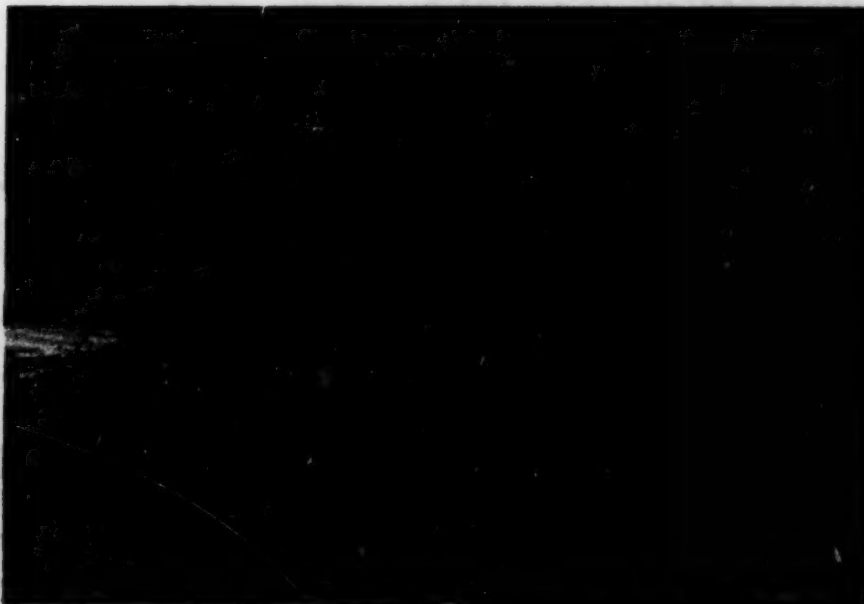
natural drainage path, that is, into the muskeg area between Gerald and Wolf Lakes. An access road across the muskeg, between the Tailings Storage Area and the Mill, was frozen at the time of the spill. Two large diameter (> 500 mm) corrugated steel pipe culverts existing in the road were also frozen full. The culverts have since been equipped with control valves.

The road was apparently constructed over the muskeg as evidenced by significant settlement of the road surface relative to the adjacent Utilidor foundations which were founded on piles. The frozen road provided an adequate foundation base to immediately proceed with the construction of a temporary dyke along the road. This temporary dyke is restricting, on a temporary basis, the potential flow of water from the muskeg area across the road and into Wolf Lake.

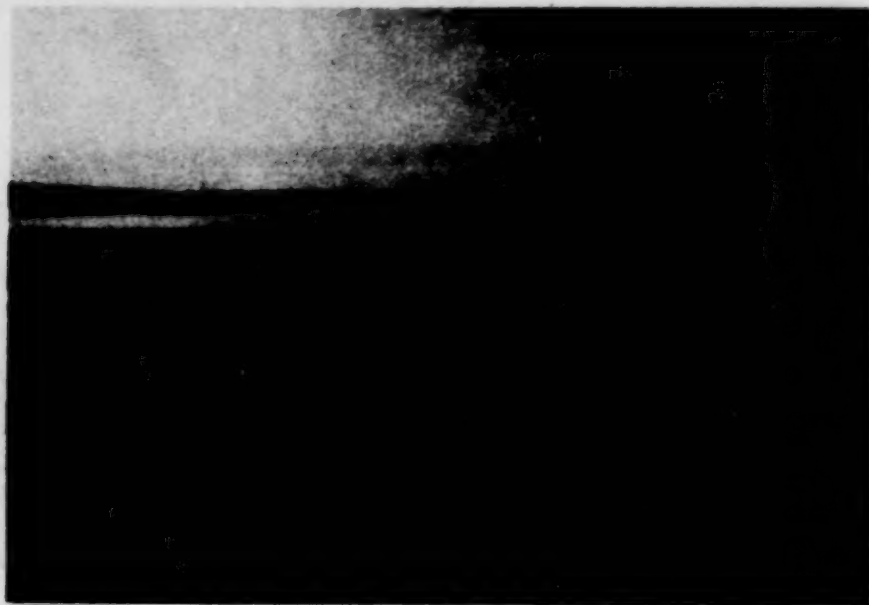
Photograph Nos. S84-649-7P and 8P show the temporary containment dyke. Photograph Nos. S84-649-9P and 10P show the flow path and entrance of the spill water at Gerald Lake.



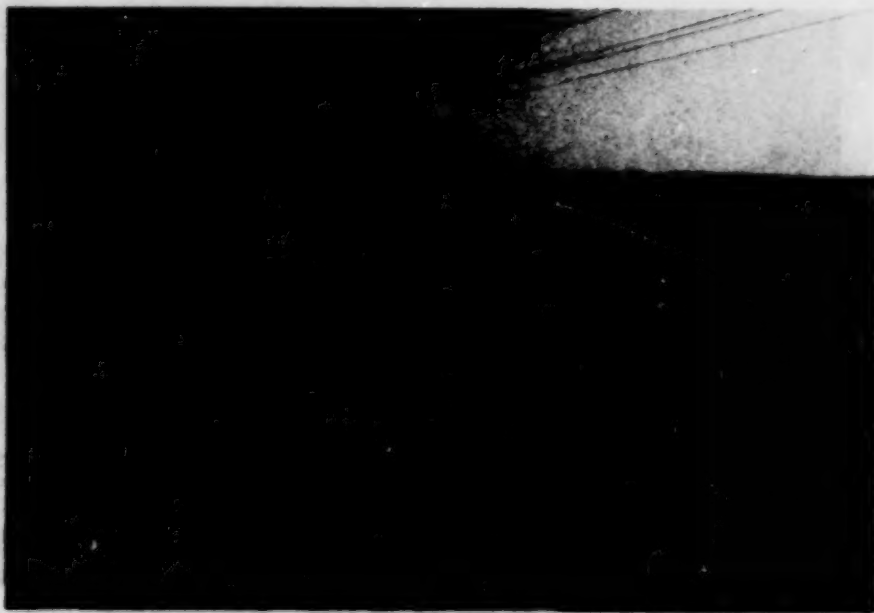
PHOTOGRAPH NO. S84-649-7P - Temporary containment dyke - view looking west. Note: Utilidor on right and Tailings Disposal Reservoir in background. (January 7, 1984)



PHOTOGRAPH NO. S84-649-8P - Widened temporary containment dyke - view looking east. Utilidor on left, contained surface frozen water in muskeg area on right, mill in background. (January 13, 1984)



PHOTOGRAPH NO. S84-649-9P - View of Gerald Lake, looking southwest. Foreground is location of spill water entrance into north east quadrant of Gerald Lake. (January 7, 1984)



PHOTOGRAPH NO. S84-649-10P - Erosion and deposition of soil along toe of west dyke of Reservoir No. 1, between breach and north-east quadrant of Gerald Lake. (January 7, 1984)

5.2 Natural Drainage Basin

An examination of aerial photographs and contour plans, and, a field reconnaissance indicated moderate topographic relief characterized by drumlins and eskers with a complex interconnected surface drainage network. Recharge is attributed to spring snowmelt, local precipitation, groundwater discharge and interconnected drainage networks. The mean annual precipitation is in the order of 400 mm.

Three levels of flow are operative in the overall drainage network surrounding the Key Lake Mine Site. These include local, intermediate and regional systems. The Mine Site lies within the local drainage system of Gerald Lake. In turn, Gerald Lake functions as the head waters for the intermediate drainage system which includes the catchment area of Wolf Lake.

The local amphitheatre shaped catchment area surrounding Gerald Lake has been identified on the site plan, Drawing No. S84-649-1. The catchment boundaries confine an area of approximately 1,300,000 square metres. The catchment area surrounding Wolf Lake which also includes the catchment area of Gerald Lake is approximately 4,500,000 square metres. The above interconnected drainage system enters the

regional drainage network outside the area affected by the Key Lake Mine Site.

Of prime concern is the local drainage system of Gerald Lake and the adjacent muskeg area. Any water (snowmelt, groundwater discharge or precipitation) which enters the Gerald Lake drainage basin will be contaminated with the Mine Spill water thereby significantly increasing the volume of water and area affected by the spill. The surface water from the intermediate catchment area north and west of Gerald Lake will flow immediately north and west of the affected area. If the water in the muskeg area is contaminated, then mixing of the headwaters would likely result and discharge into Wolf Lake would occur during the spring runoff. Based on drainage areas of 1,300,000 square metres, the total volume of spring runoff based on an estimated equivalent precipitation of 150 mm is approximately 200,000 m³ of water or more than two times the volume of the spill water.

6.0 COLLECTION AND DISPOSAL OF SPILL WATER

Several possible alternatives have been considered with respect to the cleanup of the spill. At the time of preparation of this report the spill water based on test data available was contained in Gerald Lake. Some water may have entered the muskeg area between Gerald Lake and the temporary dyke between Gerald and Wolf Lakes. A significant amount of the displaced water froze in the muskeg area. At the time of our site inspections, there was no evidence of water seepage into the Wolf Lake area. Samples have been collected from Gerald Lake and the muskeg area and chemical tests are being conducted to establish the total area affected by the spill. Once the areas affected are specifically known, then detailed cleanup plans could be formally implemented. The possible methods of cleanup are discussed in the following sections.

6.1 Pump into Reservoir No. 1

One method of cleanup is pumping the spilled water back into Operating Reservoir No. 1 which was not affected by the breach of Reservoir No. 2 Dyke. The collected spill water could be used as process water in the normal mill operation.

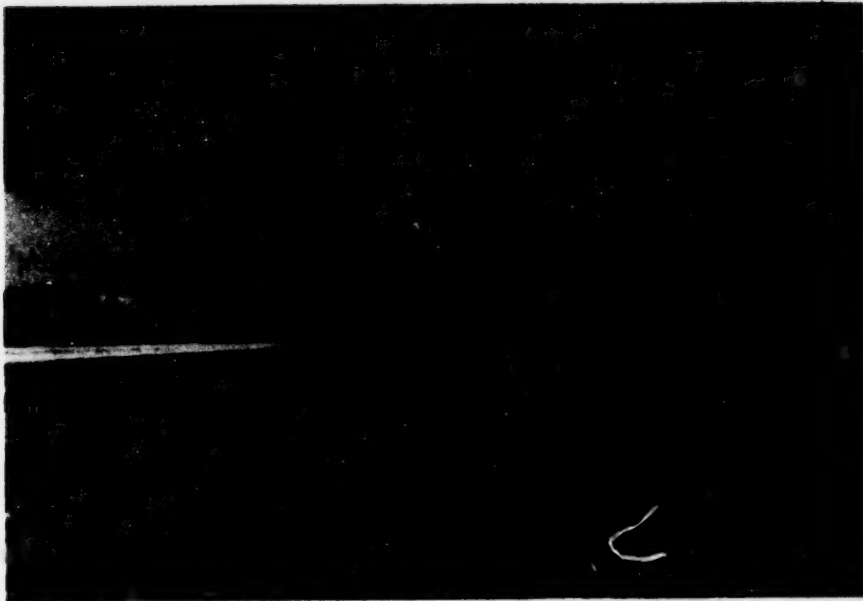
The difficulty with this proposal is that the volume of water is significantly higher than the capacity of Reservoir No. 1 since the spilled water was, to some extent, mixed with the lake and/or muskeg water outside of the Reservoirs, thereby increasing the volume of contaminated water.

Due to the large volume of water, cleanup should start as soon as possible. This would ensure that the majority of the spill water would be pumped back into Reservoir No. 1 before spring runoff which is estimated at approximately 200,000 cubic metres. Photograph Nos. S84-649-11P and 12P show the improved dyke section and preparation for pumping.

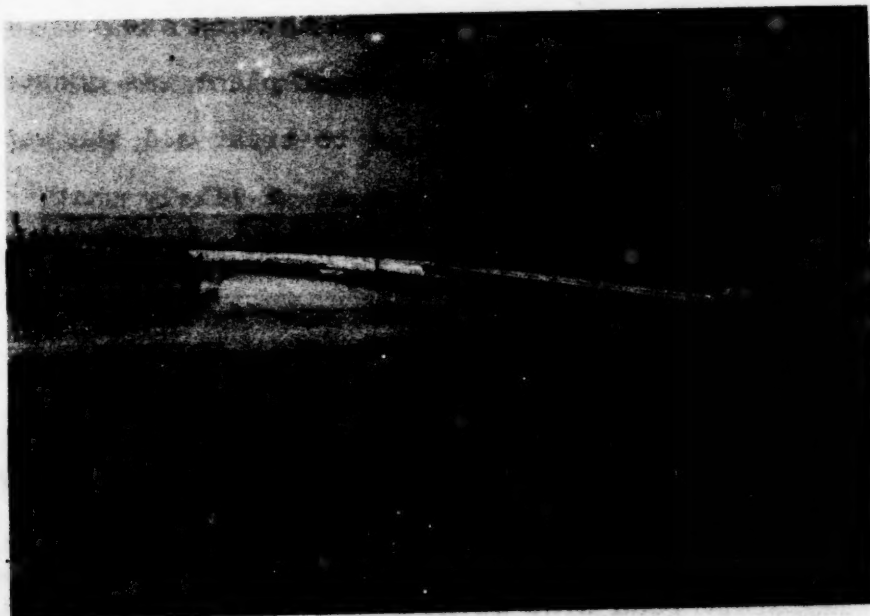
6.2 Pump into Tailings Management Reservoir

The largest capacity storage reservoir is the Tailings Management Reservoir. This reservoir is almost empty at the present time and has the capacity to hold all the spill water.

The detrimental effects, if any, on the operation of the Tailings Management Reservoir should be evaluated prior to pumping into the Reservoir. The effects, if



PHOTOGRAPH NO. S84-649-11P - Looking east at temporary containment dyke and pumping station opposite drainage culverts. (January 13, 1984)



PHOTOGRAPH NO. S84-649-12P - Looking west at temporary containment dyke and hose from collection pumping station to Reservoir No. 1 in preparation of pumping water from muskeg area. (January 13, 1984)

any, on the subsurface drainage installations as well as planned deposition of the tailings should also be considered.

6.3 Treatment of Spill Water on Site

Consideration has been given to the construction of a treatment plant to process the spill water. Although this possibility should not be ruled out at this time, and, in fact, it may be a desirable alternative, the treatment system does not rate a high priority. The reason for this is the fact that unless a high capacity treatment plant was constructed, there is not sufficient time to treat all the water before the spring runoff nor is it likely that adequate time is available to bring such a treatment plant on stream before spring runoff.

Another problem associated with an on site treatment plant is the necessity of constructing a relatively permanent dyke along the Utilidor road before spring breakup. In our opinion, the existing temporary road dyke is not adequate to retain the present level of water on a long term basis or the potential volume of water due to the spring thaw.

We do not consider it feasible to construct an adequate dyke system before spring runoff. The spring thaw will allow seepage to occur through the muskeg below the temporary dyke and road.

6.4 Control Potential Contamination of Surface Runoff

The intermediate drainage system water flows towards Wolf Lake along the west edge of the muskeg into which some of the spill water may have infiltrated. The volume and the rate at which spring melt and runoff will occur, will determine the amount of intermixing of any remaining spill water in the muskeg area.

If the contaminated water is pumped from the muskeg into Reservoir No. 1 and/or into the Tailings Management Reservoir, then the intermediate drainage spring thaw flow should not be affected. On the other hand, if the cleanup is incomplete before spring thaw and the level of contaminants is not within acceptable limits, then the spring thaw drainage water should be diverted. Sampling and chemical analysis of the remaining water in the

muskeg area should therefore be conducted as soon as practical after the muskeg is pumped out to assess the course of action before the spring thaw.

7.0 PRESENT STABILITY OF RESERVOIR NO. 1 DYKES

The theoretical computer analysis of the dyke cross sections existing at Reservoir No. 1 indicates that the drained dykes have a factor of safety of more than 2. This is considered to be a safe condition when considering slope or shear failure of the dyke. If the dyke should become saturated, then the factor of safety would decrease very significantly and erosion or piping failure could occur.

8.0 PROPOSED REPAIR RESERVOIR NO. 2 DYKE

Following initial discussions at the mine site on January 7, 1984 and preliminary approval of method of cleanup of the breached dyke section, we received a print of Drawing No. 4219 Rev. 0, entitled "Water Storage Reservoir Remedial Work on Reservoir No. 2" on January 18, 1984. We have reviewed the drawing and

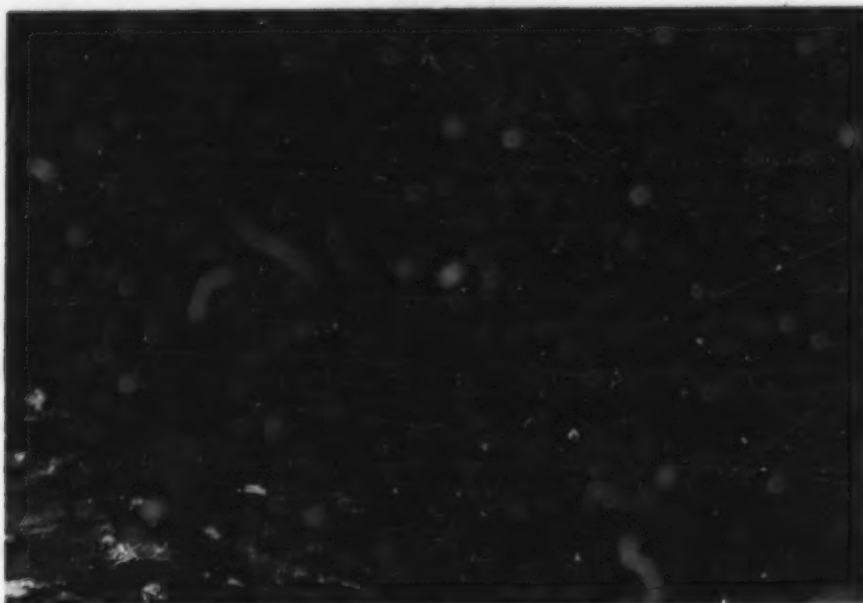
concur with the proposed remedial work required to repair the embankment.

The remedial work as detailed on Drawing No. 4219, Rev 0, will consist of the removal of the undercut portion of the dyke by sequential blasting and cleanup, followed by reconstruction of the earth fill. The proposed fill material will consist of well graded gravelly sand compacted to as high a density as practical considering winter construction conditions. The theoretical slope stability of the reconstructed dyke section based on the design parameters is in the order of 1.9. A review of all field tests should be conducted after the dyke is repaired.

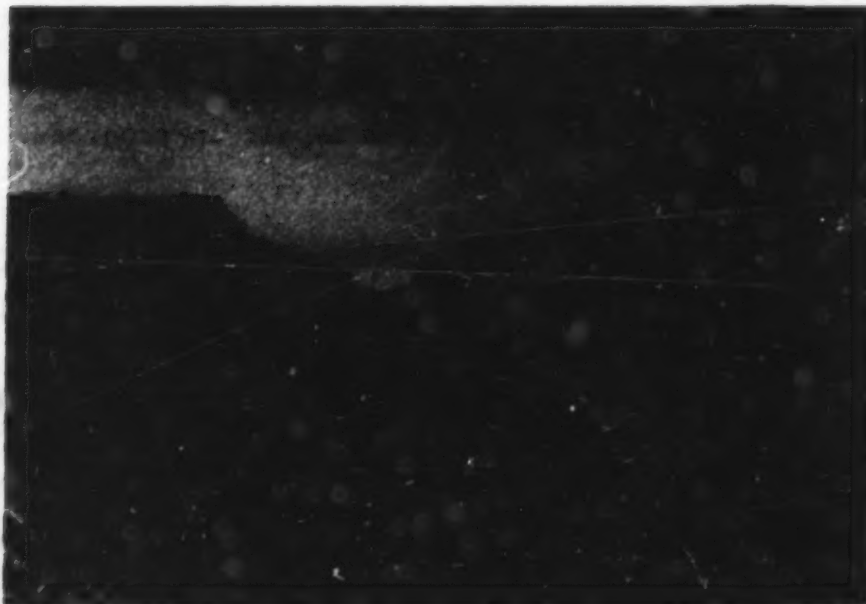
The high density polyethylene liner will be repaired upon completion of the dyke reconstruction. Photograph Nos. S84-649-13P and 14P show dyke repair in progress.

9.0 TEMPORARY CONTAINMENT DYKE

A temporary containment dyke was constructed parallel to the Utilidor along the road between the muskeg and Wolf Lake leading to the Tailings Management Area. This temporary containment dyke was constructed on the existing frozen road. There is evidence of settlement of the road when compared to the Utilidor foundations which were based on piles. It must be assumed that the road was



PHOTOGRAPH NO. S84-649-13P - Drilling north side of breached area of west dyke. (January 13, 1984)



PHOTOGRAPH NO. S84-649-14P - Cleanup of breached section of dyke. (January 13, 1984)

constructed over the existing muskeg. It is estimated that the muskeg could be up to 4 metres in thickness. The amount of settlement of the road that has occurred to date is not known. However, it is likely that settlement of the muskeg subgrade will continue to occur for some considerable length of time.

9.1 Maintenance of Temporary Dyke

The water in the muskeg area is being retained by the temporary dyke constructed over the access road. If this temporary dyke were to fail, then water behind the dyke which was not frozen would flow into Wolf Lake.

The stability of this road and the temporary dyke has been significantly enhanced by the fact that the road, the temporary dyke and some of the water behind the dyke are frozen. The structural quality of the temporary dyke is dependent on the structural quality of the road foundation. It is our opinion that the existing temporary dyke would not be capable of retaining the additional head of water from the spring thaw

without significant structural earth fill upgrading. As well, once the muskeg area thaws out, thaw water seepage through the muskeg below the road (unless the muskeg was removed) could be excessive. The road and existing dyke should be monitored on a regular basis until such time that the water level in the muskeg area is pumped down to the pre-spill level.

9.2 Maintenance of Drainage Culverts

It is understood that the two drainage culverts in the road between the muskeg area and Wolf Lake have been equipped with control valves. The control valves should allow for a controlled discharge of water from the muskeg area. These culverts should be monitored on a regular basis in conjunction with the road and temporary dyke. Photograph Nos. S84-649-15 and 16 show the culverts and the drainage ditch below the culverts leading towards Wolf Lake.

10.0 RECOMMENDED OPERATION OF RESERVOIRS

The following minimum recommendations are submitted for your consideration in the operation of the Water Storage Reservoirs.

10.1 General Considerations

Water Storage Reservoir No. 1 was designed to store process water required by the mill and surface runoff from mill site, while Reservoir No. 2 was designed to store process water as well as supernatant liquid from Tailings Storage and any recycled water from the mill operations and the monitoring ponds.

Under normal operating conditions the water level in Reservoir No. 1 would be maintained below the operating design elevation of 537.50 metres. Reservoir No. 2 should normally be operated well below the design elevation of 537.50 metres to maintain storage capacity for supernatant liquid, recycled mill water and monitoring pond water. If one of the reservoirs were to be filled above the design elevation, then the water would normally drain into the other reservoir.

The mill was brought on stream during the late summer of 1983. The mill process adjustments used up more process water than would normally be used in a fully balanced refining operation. Both water

storage reservoirs were filled and operated above the design operating elevation prior to the spill.

10.2 Minimum Freeboard

The reservoirs were designed to operate with a minimum freeboard of 1.5 metres. The design drawings show the "as constructed" dyke elevation of 539.00 metres. The actual dyke elevation at the breach was 538.8 metres. The "as constructed" spillway in the common dyke between Reservoir Nos. 1 and 2 was shown as 537.50 metres. The actual elevation was 538.2 metres. Therefore, in order for the spillway to operate, one of the Reservoirs would have to be filled to within 600 mm of the top of the "as constructed" dyke. This represents an operating level of 900 mm higher than the minimum freeboard of 1.5 metres.

To provide a minimum freeboard of 1.5 metres it will be necessary to extend the dykes to a minimum elevation of 539.7 metres. Alternately, the spillway in the common dividing dyke could be reconstructed to the lower original design elevation of 537.50 metres.

It is recommended that a freeboard of not less than 1.5 metres be maintained in both Water Storage Reservoirs at all times.

10.3 Water Level Indicator System

The Water Storage Reservoirs were not equipped with water level indicators. The mill operators did not have an instant reference, without physically inspecting the Reservoirs on a regular basis, of the water levels in the Reservoirs.

It is recommended that both Reservoirs be equipped with Water Level Indicators. The water level indicators should be equipped with a sound/visual alarm system to alert the operator when the water level reaches the minimum freeboard of 1.5 metres. The water level indicators should be designed to artificially permit checking of the indicators for their proper functioning at both a set low level and at the minimum freeboard elevation.

10.4 Mill Area Surface Drainage

The mill area surface drainage was designed to drain into Reservoir No. 1. Adequate freeboard must be maintained at all times to ensure that the necessary storage capacity is available to contain surface runoff.

10.5 Protection Against Dyke Erosion

The theoretical slope stability analyses indicate that the dykes have an acceptable factor of safety in the "dry" condition. Upon saturation, the slope stability of the dyke fill decreases dramatically. The dyke fill soil is highly susceptible to erosion.

In our opinion protection of the dyke against water erosion is necessary to maintain the dyke cross section. Erosion could occur in the event of overtopping, very heavy precipitation, or, piping due to rupture in the liner and flow of water through the dyke. An examination of the mechanism of failure of the dyke indicates that erosion of the sand particles accelerated progressive erosion and undercutting of the dyke along the underside edge of the liner. This allowed the liner to deform downward with the increasing weight of water. In turn, the increased flow accelerated the erosion. As the erosion progressed it became necessary to cut the liner to control the flow path and thereby the width of the breach as opposed to allowing the water to erode a wider section of the dyke closer to Reservoir No. 1.

One possible way of decreasing the potential erosion of the sandy dyke fill would be to extend the high density polyethylene liner over the dyke and to within 1.5 metres of the natural ground surface. The high density polyethylene liner should then be covered with at least a 6 metre wide berm of coarse graded gravel or rip-rap. This would surcharge the toe of the dyke, hold the high density polyethylene in place and dissipate any flow water energy in the event of a similar spill. The suggested coarse graded gravel or rip-rap berm should protect the earth fill dyke from the serious type of erosion experienced.

10.6 Supplementary Spill Collection and Holding Reservoir

In our opinion the probability of other spills is inevitable. Spills of variable proportions will occasionally occur at this and any other mining operation during the operating life of that facility. This is particularly true in the hostile northern environment during the winter months.

It is our recommendation that all potential areas of spills in the mill, the water supplies and the tailings disposal be reviewed in order to establish the potential maximum size of spill. A contingency plan for cleanup of any such spill should be in place. In conjunction with the contingency plan, a Spill Holding Reservoir should be constructed for that specific purpose.

11.0 CLOSURE

The foregoing report was prepared on the basis of two site inspections of January 7, 1984 and January 13, 1984, and, a review of the design drawings as well as a construction report prepared after construction of the Water Storage Reservoirs.

We did not examine or review any results from the sampling of the spill water from Gerald Lake, the muskeg area, Wolf Lake or any of the other established monitoring locations. Hence, we do not have any information with respect to the location or lateral extent of spill water migration.

This report dealt predominantly with the geotechnical aspects of dyke construction, dyke stability, dyke reconstruction and the containment measures constructed by Key Lake Mining Corporation within hours of the occurrence.

The design and construction of dykes using granular materials with synthetic liners as the only defence against seepage should be reviewed in the light of the high susceptibility to erosion and the long term performance expected of these installations in the hostile northern environment.

We believe that the recommendations submitted reflect the present status of the water spill. It should be recognized, however, that any one of several factors may to some degree affect the present equilibrium. For this reason the cleanup of the spill as soon as practical is of utmost importance.



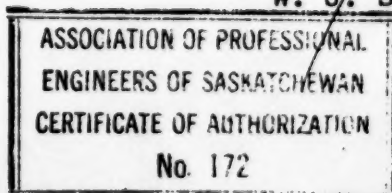
Yours very truly,

P. MACHIBRODA ENGINEERING LTD.

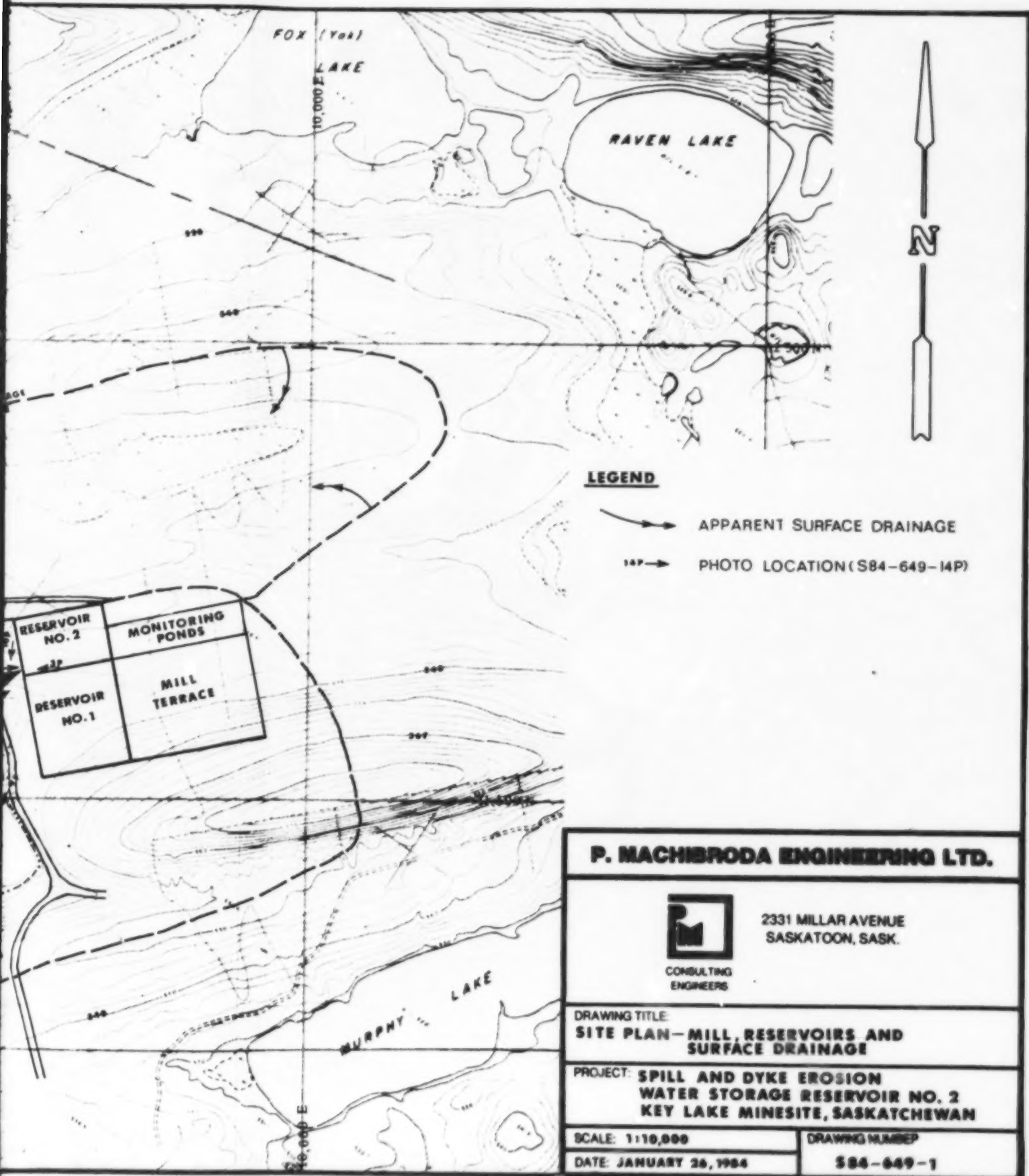
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W. J. Smith
W. J. Smith, P. Eng.

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SASKATOON, SASK.

DRAWING TITLE:
**SITE PLAN—MILL, RESERVOIRS AND
SURFACE DRAINAGE**

PROJECT: **SPILL AND DYKE EROSION
WATER STORAGE RESERVOIR NO. 2
KEY LAKE MINESITE, SASKATCHEWAN**

SCALE: 1:10,000

DRAWING NUMBER

DATE: JANUARY 26, 1984

S84-649-1

POOR

QUALITY

ORIGINAL